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RESPONSE FORCE EMISSION AS A COMPONENT OF

OPERANT BEHAVIOR

by

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A DISSERTATION

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PSYCHOLOGY

EDMONTON, ALBERTA

APRIL, 1968

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend
to the Faculty of Graduate Studies for acceptance, a dissertation
entitled "Response Force Emission as a Component of Operant
Behavior" submitted by Robert R. Haney in partial fulfillment
of the requirements for the degree of Master of Science.

ABSTRACT

Four pigeons were trained to respond on a fixed interval schedule with response rate and response force observed following attainment of behavioral stability. Both rate and mean peak response force tended to increase with time from start of interval, showing FI "curvature" to exist on both response dimensions. Equal-length alternating periods of "houselight-on" (S^D) and "houselight-off" (S^Δ) were then superimposed upon the interval component. Asymptotic response force and rate under these conditions tended to increase with time in the interval, as before, and were higher in S^D than in S^Δ periods. Correlational analysis showed this response force--response rate relationship to be almost entirely due to the effects of the reinforcement schedule. It is suggested that both rate and force emission reflect schedule-produced changes in the same underlying determinants of responding.

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INTRODUCTION

The basic dependent variable in conditioning research is some quantifiable property of response. Precisely which response property is chosen for a particular study usually depends on the ease and reliability with which such data may be observed. Although classical behaviorists attempted to deal empirically with the analysis of response amplitude, this measure was soon discarded for the more easily gathered temporal data, rate and latency. Indeed, the primary characteristic of operant conditioning experiments is "the extensive use of rate and pattern of responding as dependent variables." (Kelleher, 1965). To paraphrase Kelleher, the variables of interest in the Skinnerian tradition of behavioral investigation are the number of responses per unit time (rate) and their topography.

The time elapsing between identifiable points in the emission or elicitation of a response is termed the response latency. In the classical paradigm, latency most often refers to the time between onset of the unconditioned stimulus and appearance of the unconditioned response. The Hull-Spence approach uses points in the execution of an instrumental response as the defining borders of a latency. For example, the latency may be the time elapsing between S leaving the start box in an alley maze and his arrival at the goal box.

Data provided by the rate and latency measures have been offered in support of various learning and motivation theories. Indeed, variation in rate is often regarded as an indication that there is corresponding variation on some underlying energistic continuum. Operational definitions of concepts such as "Drive," "Habit Strength," Excitatory

Potential," "Reaction Potential," and "Motivation" seem to require a measure involving more than frequency or time. It is the purpose of this thesis to investigate another response dimension, that of response force emission, the force emitted by an organism in the execution of a response.

Response force emission has been given little attention by most experimenters. Most often the concern of investigations of response intensity have been with response force requirement, a distinctly different topic. Response force requirement refers to the response effort required for a reinforcement and this effort requirement is varied as a part of the procedure. The distinction between the two response intensity variables, force emission and force requirement, is important. Force emission refers to the amount of force emitted by $\underline{S}$ in the act of responding, whereas force requirement refers to the minimal amount of response force required of the subject for reinforcement.

The temporal response variables, rate and latency, are of proven value for use in the empirical study of behavior. The relationship between response rate and response force emission is not clear. The main objectives of this study are twofold: Firstly, we shall develop a technique for the study of keypeck response force emission, and secondly, we shall investigate the degree to which response rate and response force emission covary. Since recent technological advances have made force, or the intensive dimension of response, more amenable to observation and statistical analysis, it seems reasonable to assume that research employing a direct measure of response intensity would be of theoretical importance.

The variables response rate and force emission are not incompatible measures. A coarse analogy to this pair of variables existent in another discipline are the independent measures of cardiovascular function; heart rate and the blood pressures, diastolic and cystolic. These are independent and complimentary indices of the functioning of the heart. Blood pressure is the more specific measure,[1] but heart rate is also necessary for a valid description of the cardiovascular response at any particular point in time. So too would a sensitive response intensity measure clarify and elaborate on changes in unobserved behavioral states.

Although there are many interesting theoretical and practical issues in psychology today which might be elucidated through the experimental observation of response force, for example, experimental isolation of the effects of type and amount of reinforcement or drug on response force emission, empirical studies of response force emission are relatively few. Several reasons may account for the incompleteness of this research area. First, response rate measures have been traditional, as we have noted. Secondly, response force data are more difficult, technologically, to record than are the frequency data. Joseph Notterman's research program, culminating in the book, _Dynamics of Response_ (Notterman & Mintz, 1965), contains the most exhaustive series of studies on this variable to date. It appears that the technical complexities of obtaining this measure have until recently dissuaded many researchers who might otherwise

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[1] A series of studies by Funkenstein, 1962, demonstrated differential sensitivity of the two blood pressures to adrenalin or noradrenalin in combination with mecholyl, a parasympathetic system stimulant. The lack of differentiation in heart rate under the same conditions implies that, of the two measures, heart rate is the more gross.

be interested in the response force emission measure to work with more

technically feasible data such as response rate.[2]

The technological advance which has made response force more amenable

to empirical investigation is the miniature force transducer, commercially

called a "microducer."[3] This pressure cell consists of two small brass

shells sandwiching pressure sensitive material. Electrodes are attached

to both brass shells. The principle involved is that the resistance

offered by the filler material[4] to an AC or DC current passed through

this material will change proportionally to a force applied to either

side of the pressure cell. The change in resistance is registered on

an ohmeter.

The purpose of this study is to develop and employ a technique for

the investigation of response force emission. Specifically, this study

will investigate the effects upon force emission of alternating S^D-S^Δ

periods in a fixed interval (FI) schedule of reinforcement, a procedure

originally reported by Dews (1962).

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[2]Hefferline, et al. (1961) discuss the complexities involved in
recording free force emission and say: "The engineering sophistication,
entailed . . . makes it safe to say that Notterman's achievement will not
soon be duplicated in many other laboratories."

[3]by its producers, Clark Electronics Laboratory (CELAB), Palm Springs,
California.

[4]The material between the shells is a resinous mixture of rare earths
treated with zirconium tetrachloride which undergoes predictable changes in
electrical resistance upon physical compression (Hefferline, et al., 1961).
The manufacturer's specifications report negligible resistance changes due
to temperature variation between -20°F to 300°F and reliable sensitivity
following extended usage.

Dews has attempted to identify the determinants of the "scalloped" response pattern typical of FI reinforcement, an acceleration in response rate as time to reinforcement decreases (Ferster & Skinner, 1957). Acceleration in response rate frequently ceases in advance of completion of the interval with S reaching terminal rate somewhat before the reinforced response occurs.

Using a standard operant conditioning procedure, Dews trained pigeons to keypeck characteristically under an FI ("fixed interval") 500 sec., TO ("time out") 250 sec. reinforcement contingency. That is, the first response after 500 seconds of stimulus presentation (transilumination of the response key) is reinforced, following which the stimulus is removed for a 250 sec. "time out" period. After Ss reach behavioral stability under the FI 500 sec. TO 250 sec. contingency, an $S^D - S^\Delta$ discrimination is introduced. "S^D" and "S^Δ" refer, respectively, to the presence or absence of a stimulus that is always present when reinforcement of a response occurs, the discriminative stimuli in this case being the presence (S^D) or absence (S^Δ) of illumination in the chamber from the "houselight" (HL). In this phase of the experiment, HL alternated with no-HL for 50 sec. subintervals during the 500 sec. interval component of the cycle, and was present during the final subinterval which was terminated by reinforcement. (The response key was transilluminated throughout both S^D and S^Δ subintervals of the cycle, being unlighted only during TO periods.)

This $S^D - S^\Delta$ training had a pronounced effect on the FI scallop. The average rate of responding under S^D was approximately 3.5 times as great as the average rate under S^Δ and the appearance of either S^D or S^Δ response

curves, when viewed separately, was that of the scallop. Dews interprets these $S^D - S^\Delta$ effects on FI responding as contrary to those expected from a "response chaining" explanation of the scalloped pattern of responding.

It was believed that such experimental manipulations might similarly produce a marked effect on force of responding and were therefore employed in the study to be reported here. The present study is a modification of the Dews study, employing an additional response measure, force, but essentially the same experimental conditions.

There are two parts to this section. The first and more extensive portion deals with literature concerned with the force intensity variable. The second part outlines literature relevant to the production of the FI scalloped pattern of behavior.

Empirical work with response amplitude is found in the classical Pavlovian salivation studies (e.g., 1927). A salivary reflex was conditioned to a tone of a certain frequency, following which tones of different frequencies were introduced. The salivation reflex generalized to other tones proportionally to the relative difference of each from the conditioned tone, although the explanation of this phenomenon offered by Pavlov, that of cortical irradiation, appears premature.

Variation in amplitude of other responses under the control of the autonomic nervous system has been used as an empirical basis for theory. Clark Hull uses an increase in amplitude of the galvanic skin response over trials of shock-tone pairings (Hovland, 1937) as a basis for his habit strength ($_SH_R$) construct: "Accordingly, the amplitude of the reaction is said to be an increasing function of the number of reinforcements." (Hull, 1943).[1] Amplitude of the eyeblink response has also been used as evidence for theory but Spence prefers frequency measures. His criticism that there are "a number of factors which made for highly unstable conditioning curves . . ." (Spence, 1956) is directed specifically

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[1] Hull's explanation for a constant level of response amplitude is that the physiological limit (M) of habit strength ($_SH_R$) has been reached. Decelerating amplitudes may be explained as ($_SH_R$) approaching M.

at eyeblink conditioning amplitude data but appears to reflect his

attitude toward amplitude measures in general, as evidenced by the

infrequent reference to such data in his book.[2]

B. F. Skinner, considered by many to have given impetus to the

operant tradition of behavioral investigations, initially was interested

in amplitude or "intensity" of response. His apparatus was far from

complex, consisting of a lever attachment of the bar in an experimental

chamber to a pen, writing on a roll of paper which moved at a constant

speed (Skinner, 1938).[3] He equated depth of bar depression with force

exerted (a reasonable assumption if resistance offered by the bar was

constant throughout the length of its excursion) and reported intensity

of bar press responding to increase with force requirement for a reinforced

response, but rate to remain constant.

The procedures used to investigate response force emission were little

refined in the twenty year period following the publication of Skinner's

book. Many studies involved manipulation of the effort requirement of the

bar press response. For example, Mowrer & Jones (1943) showed resistance

to extinction to decrease as the force requirement for a reinforced

response is increased. Variation of the effort requirement for a

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[2]Hull (and Spence, to a lesser extent) limited their treatment of
amplitude of response to those effector systems under the control of
the autonomic nervous system because, in the case of the central nervous
system responses, Ss may be conditioned to respond with a particular
amplitude. Spence points out however that certain responses in this
latter group may be reflexive enough to preclude this argument (e.g.,
classical defense eyeblink).

[3]This device is presently known as a cumulative recorder, the only
exception being that the distance of pen excursion for a response on a
cumulative recorder is constant, whereas on Skinner's 1938 recorder,
that distance was a function of force of bar depression.

reinforced bar depression is accomplished by the attachment of weights to the response bar fixture such that as the bar is depressed, whatever loading has been selected is lifted vertically by the force of the bar depression. Logan (1959) criticizes this procedure on the basis of his assumption that the S is required to go through an acquisition phase each time the loading is varied as he is required to learn different micromolar responses for different force requirements. Kimble (1961) notes that as the force requirement for a reinforced response is raised, more responses below the required magnitude occur, hence uncontrollably introducing a partial reinforcement schedule.

In the present study, force requirement for a reinforced keypeck response will not be varied, thereby skirting the Logan objection. The very low value of this force requirement also minimizes the extent to which uncontrolled contingencies exist in the reinforcement schedule.[4]

Motivation theory has engendered a number of procedurally interesting attempts to isolate response intensity factors. The Columbia Obstruction Box developed by Warden (1931, see also Hall, 1961) required Ss to cross an electrified grid, thereby receiving shock, to obtain food, water, sex. The variable of interest was the number of times Ss would cross the grid to receive reinforcement. There have been other variations of the obstruction method: Sand and paper (Stone, 1937) were used in an attempt to eliminate the fear reaction to shock inherent in Ss after previous shock experience.

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[4]As FI requires solely one response of sufficient magnitude to occur for reinforcement, specifically at the end of the interval, the number of sub-force threshold non-reinforced responses which will occur should be exceedingly small.

Brown (1948; see also Cofer & Appley, 1964) used a response intensity measure to test the "goal-gradient" hypothesis of approach and avoidance offered by Neal Miller (1944, 1951). Rats were trained to run down a short alley either to food reward or to avoid shock. Fitted with a harness to record strain, the rats were shown to pull harder as the goal approached under either condition and that strength of the avoidance-motivated response increased more rapidly than did that of the approach-motivated responses.

It seems reasonable to assume that the procedures mentioned above have spurious effects on the responses emitted by Ss. For example, in the Brown study (1948), the rat fitted with a harness can hardly be regarded as responding to the same stimulus conditions that existed in the pretest or harness-free training period. The point is that the very act of assessing response intensity may engender behavior, whether by electrified grid obstructions, response lever loadings, restrictive harnesses or any other of the large number of similar procedures. These procedural artifacts then cause the intensity data to reflect environmental conditions other than those of immediate experimental interest.

For the most part, the research interest in the effects of varying task effortfulness variation has waned in the last ten years and the effect of reinforcement scheduling on response force emission has been studied more recently. Robert Herrick has developed a force-sensing response lever specifically "to study the intensive properties of lever-pressing behavior of rats in an orbiting statellite." (Herrick, et al., 1962). This device has been used to study the response force engendered

by several reinforcement schedules,[5] but steady state methodology is
not employed. The Herrick lever appears to have two weaknesses; insuf-
ficient flexibility to record the force in medium to high rate responding
and a maximal lever displacement which, if exceeded by the S's response,
may not record the true response value. Herrick does not speak to these
points.

The Notterman studies[6] represent the most concerted research effort
to date on the response force emission variable. The sensing and
recording apparatus used by Notterman is more complex than those used
by the other experimenters reviewed in this section (Notterman & Mintz,
1965, Chpt. 2; see also Hefferline, et al., 1961).

In addition to the frequency measures taken by digital counters and
cumulative recorder, Notterman observes three intensive properties of
the bar press response (force, duration, and the time integral of force)
which are simultaneously calculated and recorded by an analog computer.
Variable voltage from a lever strain gauge defines the duration of
computer operation and also is the input data. Sequentially, the pattern
is as follows: S presses the response lever causing DC voltage flowing
through the strain gauge to increase which in turn sets the Computer in
operation until the voltage falls below a pre-set value, whereupon the
Computer cycles into a nonoperate stage. While the Computer is in the

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[5]continuous reinforcement (CRF), Herrick, 1963; fixed ratio (FR)
Herrick, 1965; variable ratio (VR), Herrick & Bromberger, 1965.

[6]1959, 1960, 1962, and Di Lollo, et al., 1965. Added to these is
the large amount of previously unpublished data referred to in the book
Dynamics of Response (1965) co-authored by D. E. Mintz.

operation phase, the voltage analogue of the forementioned response

measures are quantified. Simultaneous print-out of these three data

is also accomplished by another component part at the same time in

this cycle.

Notterman & Mintz (1965) describe the effect of many environmental

manipulations on response magnitude. Data arising out of tasks involving

avoidance behavior, schedule control, discrimination, and differentiation

lend support to these authors' contention that there are "significant

experimental or theoretical questions best answered by examination of

the dimensional characteristics of the response itself rather than by

study of the time interval between responses." (1965, p. 3). For example,

data from the avoidance study indicate showed demonstrable differences in

the intensive properties of the bar press response (notably, lower peak

forces and shorter response durations) produced by the higher level of

shock[7] under reversal conditions. The data concerning force emission

under FI is indefinite however, as only FIs of fairly short duration were

used and this treatment was confounded by manipulation of the response

force requirement variable for the same Ss.

Very few response force studies have used pigeons as Ss. Cole (1965)

and Chung (1965) both employed the keypeck response but the latter simply

examined the effects of response force requirement on response rate, a

procedure discussed earlier in this section.

The Cole study examined the effects of different force requirements

on both rate and response force data obtained during a generalization task.

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[7]1mA to 3mA. (Notterman & Mintz, 1965), Chpt. 12.

This investigation reported force and rate generalization gradients to have a similar form but that the force gradient shape is a function of effort requirement whereas the rate gradient slope shows no such dependency. Interpretation of these results however is made difficult by the lack of clarity with which the procedure is presented. Cole used a crystal transducer of his own design to observe response force emission. It is felt that the Cole key, comprised of piano wire and a phonograph crystal, would be less easily duplicated than would the key design employed in the present investigation.

Having surveyed the literature dealing with response force emission, we shall now briefly examine the topic of fixed interval responding.

"In a fixed interval schedule of reinforcement (FI) the first response after a designated interval of time is followed by a reinforcing stimulus." (Ferster & Skinner, 1957, p. 133). These authors report several possible explanations for the typical FI "scalloped" pattern of responding. Figure 3a shows select cumulative response records of this scalloped pattern, namely, increasing response frequency throughout the interval while the terminal rate may or may not be accelerating.

The first explanation for the typical pattern of fixed interval responding is that of "response chaining" as offered by Ferster & Skinner. The view of these authors is that such response patterns are a sequence in which each response functions as a discriminative (or eliciting) stimulus for the next response in the chain until the terminal (or reinforced) response occurs, in such a way that each response changes the probability of occurrence of a further response.

Other contingencies reported by Ferster & Skinner to result from an FI schedule of reinforcement and which may therefore control the "scalloped" response pattern are:

1) Differential reinforcement of low response rate early in the interval by the reinforcement of responses following pausing.

2) Correlation of a given rate of responding with reinforcement and of another (low) rate with nonreinforcement.

3) In stable FI performance, in which the rate is zero or very low following reinforcement and builds progressively, the actual number of responses will be fairly constant across intervals.

   If this number of responses is important in determining behavior, then any responding which brings the number of responses closer to this value will be reinforced.

4) Duration since preceding reinforcement is relatively constant in a fixed-interval schedule but it is suggested that the elapse of this time acts through mediating behavior. Ferster & Skinner are not explicit as to the procedure through which this time-since-reinforcement factor would be thus operative in the progressive increase of response rate.

5) Stimuli associated with the presentation and consumption of reinforcement also trigger an occasion upon which a response is never reinforced. The effect of this contingency is to delay the start of responding and to commence responding at a low rate.

Another explanation for scalloped responding cited by Dews is that mediating responses between two events serve to transmit the behavioral influence of one event to that of the other. "These events may be responses, and the influence transmitted in time forward, as in the postulated mediating behavior between recorded responses on a DRL schedule. . ." (see also Ferster & Skinner, 1957, p. 729).

The proposed relationship between mediating behavior and chained responses is that the former is comprised of the latter, with the early members of a response chain affecting the later members through mediation by the intermediate members. However, as Dews (1962, 1966) has adequately demonstrated, this is not a tenable hypothesis since disruption of the response chain did not lead consequently to a disruption of the progressive increase in response rate during the FI.

Another explanation of the FI scallop is offered in terms of inter-response times (IRT) (see Morse, 1966). The time between successive responses may be considered either as a stimulus controlling responding or as a conditionable property of behavior. Regardless of which point of view one takes, the basic interpretation of the function of IRT in the fixed interval is that a longer IRT has a higher probability of reinforcement early in the interval than does the shorter IRT but, as the interval progresses, the probability of reinforcement for shorter IRTs increases with the elapse of cycle time.

The data reported by Dews (1962) indicated to him that no one of the above explanations of the scalloped pattern of FI responding is appropriate. Rather, the data suggest "an underlying (temporal) gradient of increasing tendency to respond that continues through the interval. . . ." He restates

this explanation: "(Increase in rate of responding is) based on a declining retroactive rate-enhancing effect of the reinforcing stimuli as the delay between response and reinforcement is increased."

The basic data supporting the "time-gradient" hypothesis offered by Dews is that there is increased responding with elapse of cycle time both in S^D and $S^\triangle$, even though there was a marked difference in rate between S^D and $S^\triangle$ responding at any equivalent time. Dews notes that his conceptualization is limited in concern to a gradient having temporal parameters, thereby being "susceptible to quantitative validation." It is reasonable to assume therefore that data arising from an intensive measure of the responding engendered by the $S^D - S^\triangle$ contingencies used by Dews would be reflective of a force gradient in fixed interval responding, if such does exist.

The preceding review of the literature dealing with fixed interval responding is intended to very briefly outline the rationale for the Dews (1962) study dealing with response rate and preface the following study dealing primarily with response force.

METHOD

Subjects

Four male racing homer pigeons, 1 to 2 years of age, were used in this study. Three of these were experimentally naive (numbers 7, 8, and 12) while the other had prior experience on a color discrimination task (number 3). Each S was maintained at approximately 80 per cent of its free-feeding weight throughout the study. Water was always available in the home cages, but never available in the experimental chamber.

Apparatus

A standard pigeon chamber was used, equipped with a response key transilluminated by white light except during time-out (TO) periods, and a feeder which allowed the S free access to food pellet reinforcement for a controlled period of time. All reinforcements in the study proper consisted of 7.5 seconds access to food. The insulated chamber was sound resistant and a 95 decibel[1] noise provided by the exhaust fan was present at all times in the chamber. The basic experimental schedule was FI 500 seconds TO 250 seconds programmed by electro-mechanical relays and timers. That is, the first response made on the transilluminated key after 500 seconds from start of cycle activated food presentation for 7.5 seconds. Following food presentation, there was no light in the chamber for 250 seconds, then the key was transilluminated and the next cycle commenced.

A daily session consisted of eleven of these FI TO cycles, responses made during the first cycle not being recorded.

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[1] As indicated on the Type 1400F, Dawe sound intensity meter.

A panel of ten Sodeco digital counters recorded frequency of response occurring in successive 50 second sub-intervals of the cycle. That is, the first counter accumulated all responses occurring in the first fifty seconds following transillumination of the key in the ten intervals; the second counter cumulatively recorded all responses which occurred during the second fifty second period in all ten intervals, and similarly for the remaining counters with each accumulating responses for a specified portion of each of the 10 intervals. These sub-intervals will be referred to in Figures 5 and 6 by the numbers of their chronological sequence, namely, numbers 1-10.

A graphic record of responding was also obtained by a Davis cumulative recorder which was operative during the FI portion of the schedule, and inoperative during either reinforcement or TO. A downward angular "pip" on the record indicates reinforcement (see Figure 3).

Response intensity was measured by a Clark Electronics "microducer" or miniature force transducer, model CS-1-51. A nine volt power source continuously passed current through the microducer. This current was unimpeded while no responses were made. However, when a response was made, a lever arrangement (see Figure 1) transmitted the response force to the microducer. Compression of the microducer in this way changed the impedance characteristics of the device such that resistance increased proportionally to the response force. A Mark II Brush recorder picked up these resistance changes and , by pen excursion in wave form, registered resistance change for each response upon a chart moving at 0.5

centimeters/second,[2] such that the greater was the resistance change, the larger was the excursion.

Each response thus activated two independent sensing devices; one, closure of a micro-switch which pulsed the controlling circuitry, Varian recorder and digital counter; the other, depression of the microducer which transmitted resistance data to the Brush recorder.

During the S^D periods of experimental phase II, the differentiating stimulus, "houselight" (HL), was provided by a No. 1820[3] bulb mounted on the panel carrying the response key and feeder.

Procedure

Each S was maintained at 80 per cent of his body weight measured after one week of ad libitum access to food.

Initial training comprised magazine training and "shaping" of the pecking response. The procedure used was identical for all Ss.

Following shaping of the pecking response (see Ferster & Skinner, 1957, p. 31) S was put on program control and reinforced for each key peck of sufficient magnitude to operate the response key microswitch.[4]

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[2]Various chart flow speeds were tried prior to collection of the data presented herewithin. The speed used (.5 cm/sec.) proved to be the best combination of compactness of record and differentiation between successive pen excursions.

[3]General Electric, 28 Volt, .10 Amp.

[4]Contacts in the microswitch were closed by a relatively small movement of the key. The effort requirement was well below the mean response amplitude of any S and was .04 of the greatest response amplitude observed during the course of the study.

After three daily fifty response sessions on this continuous reinforce-

ment schedule, the third phase of training was introduced.

The first response occurring after three minutes was reinforced

(FI 180 sec.) and reinforcement was followed by a 1.5 minute period

in which the response key was not illuminated. This latter condition

served as a "time out" period, described by Ferster and Skinner (1957)

as "time during which the animal characteristically does not engage in

the behavior being studied." Five days on this schedule, with each daily

session consisting of twenty reinforcements, was adjudged sufficient to

insure that introduction of $\underline{S}$ to the first experimental phase, an extended

FI —TO schedule, would not result in extinction of key pecking. Hereafter,

$\underline{S}$ experienced daily experimental sessions of two hours and twenty minutes

duration with approximately twenty-two hours between consecutive sessions.

There was no interruption in the daily sessions until completion of the

study.

Experimental phase I consisted of training on an FI 500, TO 250

schedule until the $\underline{S}$'s behavior was considered to have stabilized. A

daily session consisted of eleven of these FI 500" – TO 250" cycles with

only data from the last ten cycles included in the behavioral stability

criterion computation.[5] The exclusion of the first cycle data was in

part determined by the erratically higher rates typically observed in the

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[5]For a full discussion of the problems associated with each the
exclusion of some types of data from analysis and the use of criteria of
behavioral stability, the reader is directed to Chapters 8, 9 in Murray
Sidman's Tactics of Scientific Research (1960).

first interval of FI responding, reminiscent of a "warm-up" effect.[6]

Dews also included this data treatment procedure in his study.

The criterion of behavioral stability employed in this study was

defined by Schoenfeld, Cumming, and Hearst (1956) as follows:

> The first seven days on any schedule are not considered in
> computing stability. For the next six days the mean of the
> first three days of the six is compared with that of the last
> three days; if the difference between these means is less than
> 5 per cent of the six days' mean, the bird is considered to
> have stabilized and is shifted to the next schedule. If the
> difference between submeans is greater than 5 per cent of the
> grand mean, another day is added and similar calculations are
> made for that day and the five immediately preceding it. Such
> extensions of the experiment and calculations of stability are
> continued daily until the bird reaches the aforementioned 5 per
> cent criterion.

The procedure followed in this study differed from the above only in that,

following satisfaction of the criterion of behavioral stability, a record

of force emission was taken of the entire fifth interval for fifteen

consecutive days.

The fifth interval was chosen for force emission observation because

the behavior observed would be least affected by either "warm-up" or

"satiation" effects by virtue of its being the middle interval of each

daily session. These effects would more likely be present at either

end of each daily session.

Experimental phase II began on the first day following the fifteen

day force emission observation period. The schedule remained as a

FI 500 sec., TO 250 sec. cycle, but now the houselight (HL) was present

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[6]Visual inspection of the cumulative records seems to substantiate
this conclusion. The rate was characteristically higher on the first
interval of eleven for all Ss.

during the alternate 50 sec. subintervals 2, 4, 6, 8 and 10 of the FI

component of the cycle. At the end of the tenth subinterval, which was

also the end of the interval, the HL remained on until the first response

to occur after the interval had been reinforced. In this phase of the

study all reinforcements were presented in the presence of HL. This

procedure was continued until the Ss behavior met the forementioned

criterion of stability, and until completion of the fifteen session

force emission observation period which following stability. The study

was terminated at this point.

side   **top**

MICRODUCER

PIVOT ⟶

ADJUSTMENT SCREW

⟵ MICROSWITCH

FORCE ⟶

actual size
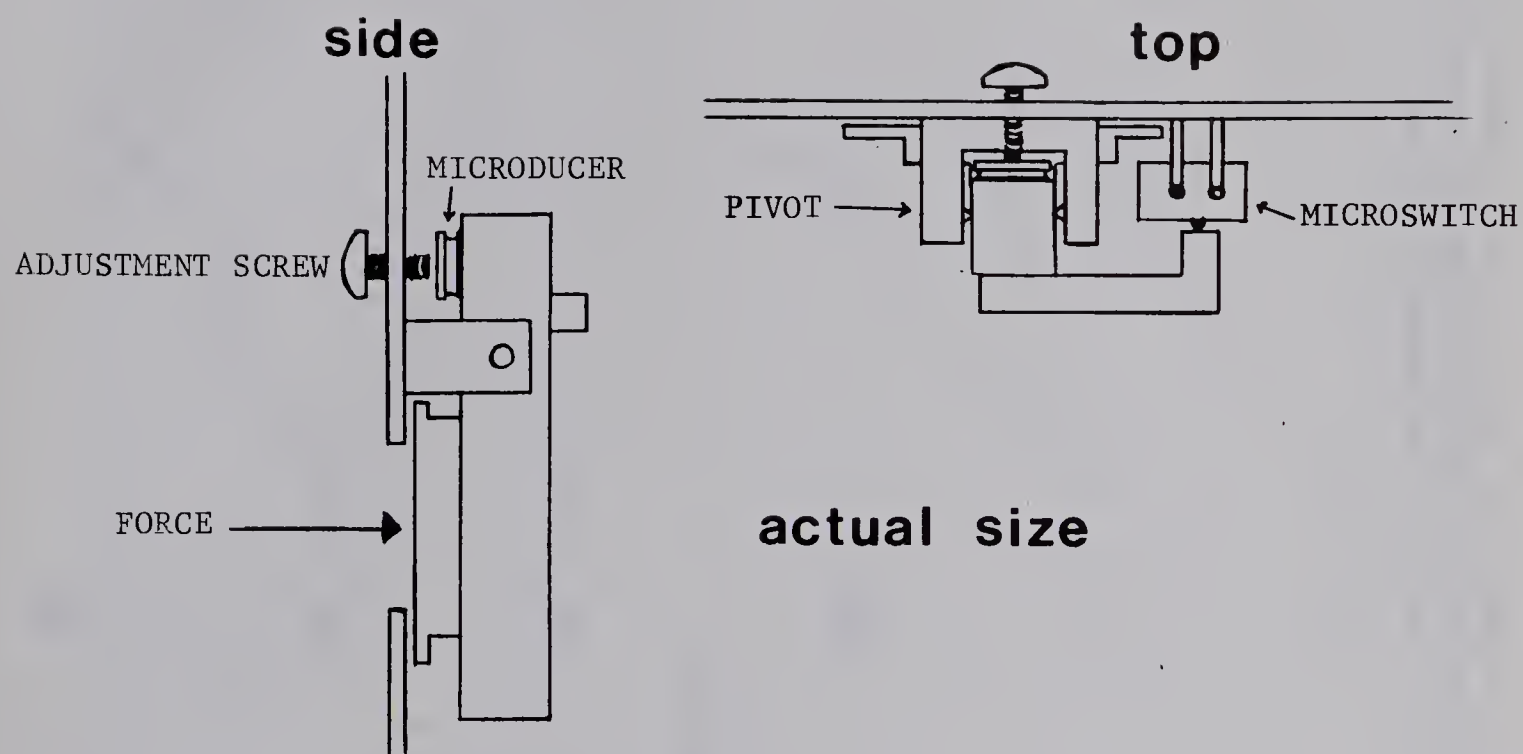
Fig. 1. The pigeon key used to detect force of peck.

300 K

MICRODUCER

TO RECORDER

9 V

100 K
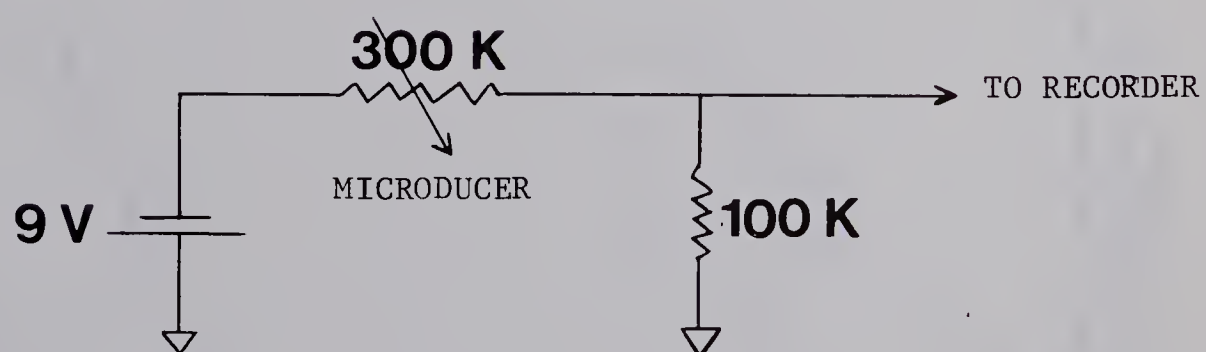
Fig. 2. Schematic drawing of response force measurement electrical
circuitry.

Fig. 3. Selected cumulative response records for each S showing behavior engendered by phase I conditions (a) and phase II conditions (b). The small downward strokes of the recording pen indicate occurrence of the reinforced response after which the paper feed stopped for the 250 sec. time-out period.
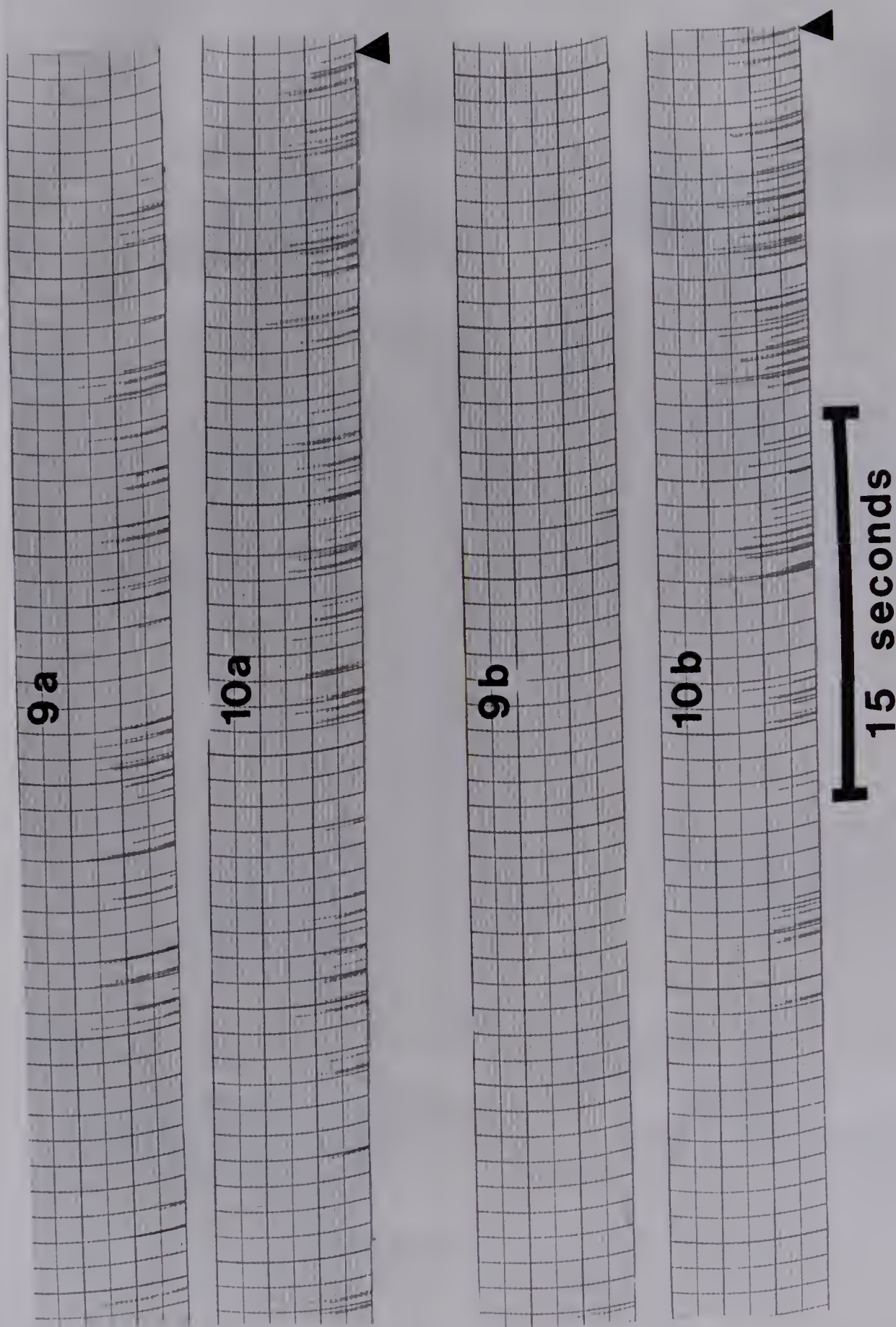
Fig. 4. Illustrative response force records for S8 in ninth and tenth 50 sec. sub-intervals during fixed interval conditions (a) and fixed interval with SD-S▲ discrimination conditions (b). Small arrow indicates reinforced response in both conditions

MEAN NUMBER OF RESPONSES

■ HOUSELIGHT
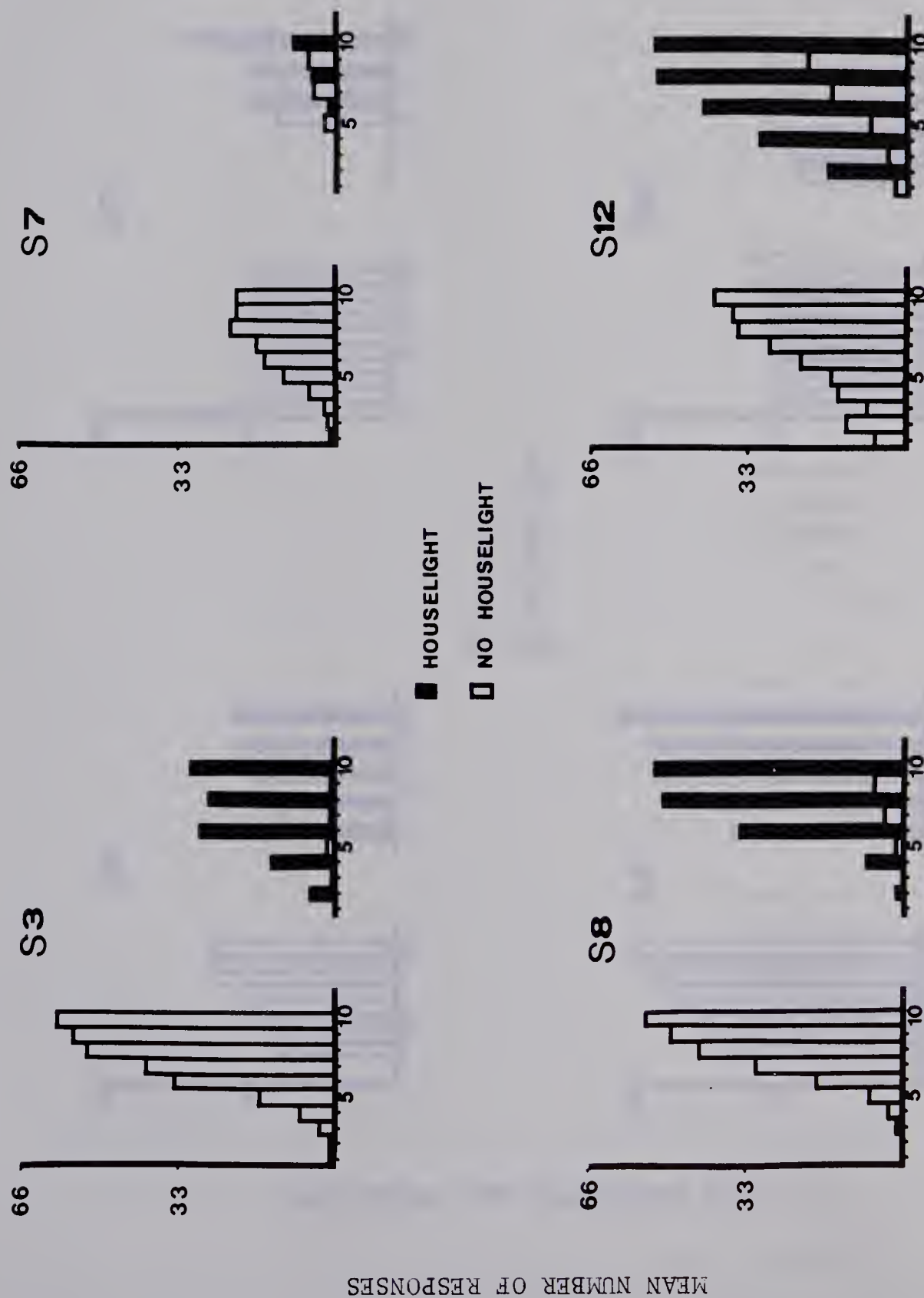
☐ NO HOUSELIGHT

Fig. 5. Mean number of responses emitted by each S in successive 50 sec. sub-intervals of the sixth
FI component in the daily experimental session. Data are based on all fifteen observation
periods in phase I (no houselight) and phase II (alternate "houselight-on" sub-intervals),
respectively.
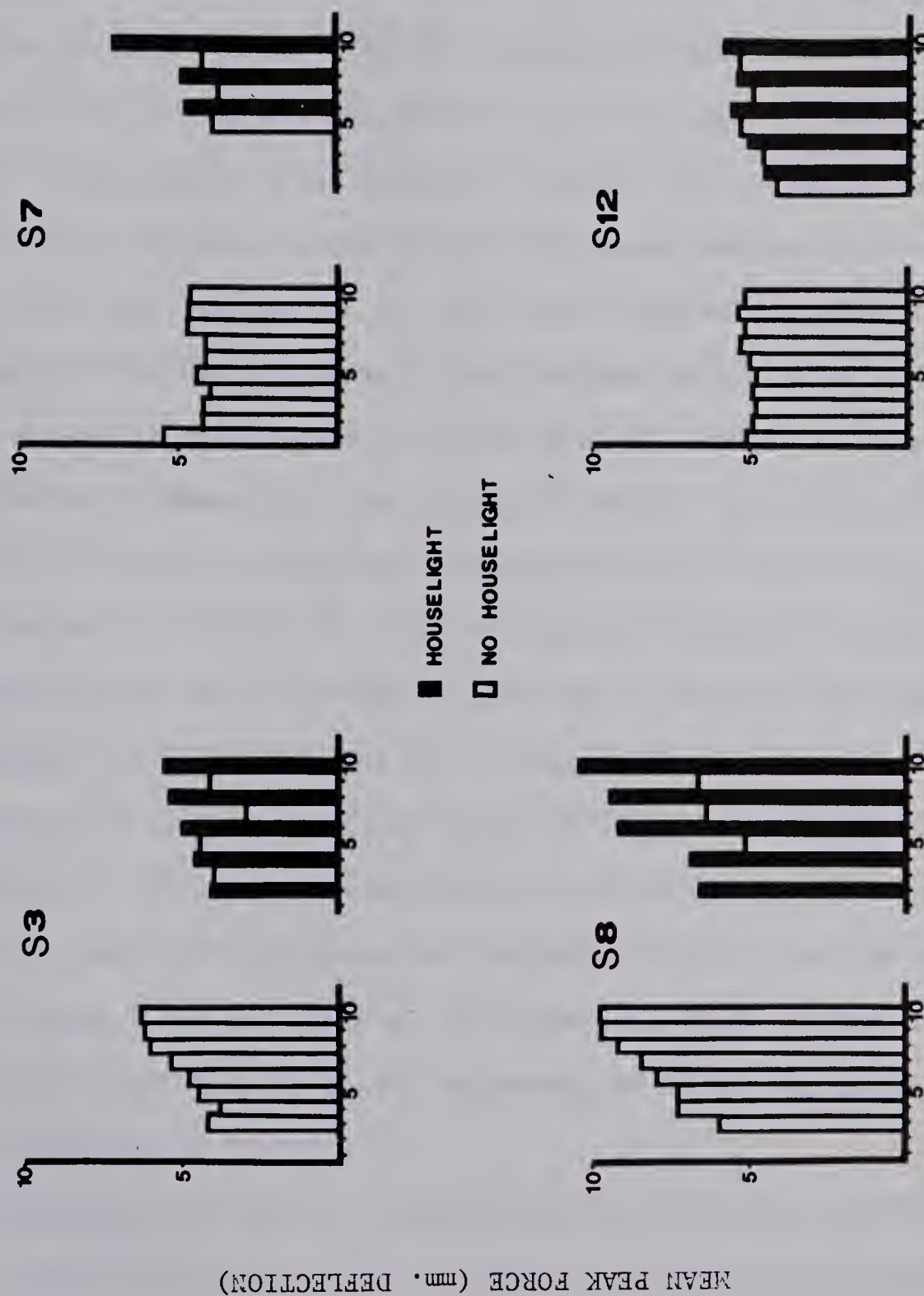
Fig. 6. Mean peak response force for each S in successive 50 sec. subintervals of the sixth FI component in the daily experimental session. Data are based on all fifteen observation periods in phase I (no houselight) and phase II(alternate "houselight-on" sub-intervals), respectively.

Ss differed with respect to the number of experimental sessions each was given before the requirements of the criterion of behavioral stability were met (see Method section). The number of daily sessions to criterion under phases I and II conditions respectively are: for S3, 59 and 21; for S7, 66 and 14; for S8, 47 and 17; and for S12, 59 and 16. Figure 5 displays the total number of responses occurring in the fifteen observations intervals, broken down by S, phase, and sub-interval. It may be seen that, except for S7, there was a general increase in response rate as the interval progresses, with terminal rate reached shortly before moment of reinforcement. Under phase II conditions response frequency was considerably less during S^{Δ} periods than during S^{D} periods for Ss 3, 8, and 12, though the response frequency of S7 did not appear to differentiate S^{D} from S^{Δ}. Thus the marked variation in response frequency due to the $S^{D} - S^{\Delta}$ discrimination, as reported by Dews (1962) was achieved in this study for all Ss except S7. Examinations of individual cumulative response records indicated that responding during S^{D} sub-intervals tended to be distributed as miniature FI "scallops". Figure 3 exhibits selected representative cumulative response records for each S under phase I (a) and phase II (b) conditions. This within sub-interval curvature is most evident in the responding of S3 and S8, as suggested by close inspection of Figure 3.

The response variable of central importance in this study, response force, showed patterning similar to that just reported for response frequency. Specifically, as displayed in Figure 6, Ss tended to respond with more force both later in the interval and during S^{D} sub-intervals.

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Under phase I conditions, force of responding clearly increased for

$\underline{S}$s 3 and 8. This trend is less noticeable, although present, for S12,

and is lacking altogether for S7. In phase II, all $\underline{S}$s tended to

respond with more force in S^D periods than in $S^\triangle$ periods. The appreciable

$S^D - S^\triangle$ response force differentiation by S7 shown in Figure 6 strik-

ingly contrasts with the lack of response rate differentiation by

this $\underline{S}$ under the same conditions as shown in Figure 5.

It will be observed in Figures 5 and 6 that while response rate and

response force both show the same pattern of variation as a function of

sub-interval, the pattern is more pronounced for the rate variable. This

difference between rate and force in susceptibility to sub-interval effects

may be examined statistically by computation of the coefficient of vari-

ation[1] for the sub-interval means on each variable for each $\underline{S}$ in each

phase. This statistic is a standardized standard deviation, one that

"tells how large the differences among scores on [a variable] tend to

be . . . in comparison to their average magnitude." (Rozeboom, 1966).

The average of the eight coefficients of variation for each variable

were .733 for rate and .257 for force. In other words, variability of

response rate due to sub-interval effects was, on the whole, approximately

three times as great as that of force.

Inasmuch as both response measures, rate and force, were similarly

affected by the independent variables in this experiment, it is evident

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[1]The coefficient of variation is mathematically defined as the ratio
of the standard deviation of a distribution to its mean. For a more
exhaustive discussion of this statistic, see Rozeboom, Foundations of
the Theory of Prediction (1966), pp. 46-47.

that they are at least to this extent positively correlated. In order

to examine the response force-response rate relationship in greater

detail, a correlational analysis was carried out on the data. For

purposes of this analysis, the data collected from each S in each

phase of the study were arranged according to a 15 x 10 matrix repre-

senting the ten periods per day within which responses were recorded on

each of the last fifteen days in that phase. For each cell of this

matrix, corresponding to one fifty-second sub-interval of the sixth

cycle in one daily session, three quantities were computed summarizing

the behavior there observed: (1) the number of responses occurring

within the sub-interval on that day; (2) the mean peak force of these

responses; and (3) a measure of force variation. This latter quantity,

sub-interval force variation, is the standard deviation of the mean

peak response forces occurring within that sub-interval corrected for

sampling bias[2] and will subsequently be referred to as "local force

variation" (LFV).

In principle, each of the eight data matrices just described provides

an array of 150 joint observations on the three response variables, from

which the intercorrelations among these variables may then be computed.

In practice, however, values for response force and LFV remain undetermined

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[2]The correction for sampling bias results from the substitution of
n-1 for n as the divisor in the formula

$$S.D. = \sqrt{\frac{\sum_{i=1}^{n} (x-\bar{x})^2}{n}}$$

where the x_i are the n values of mean peak response force obtained in the
sub-interval, and gives an estimate of the standard deviation of the hypo-
thesized population underlying the sample of observed forces.

in some instances. Specifically, for cells having a response frequency

of zero, both force and LFV are undefined, while for cells in which

frequency equals one, LFV is undefined. Consequently, only those cells

in which frequency ≥ 1 were included in the correlational analysis. The

actual number of well-defined joint observations in each data matrix,

by $\underline{S}$ and phase, are: S3, 97 and 74; S7, 106 and 86; S8, 78 and 87;

and S12, 142 and 124. With the exclusion of cells with frequency < 2,

the correlations among the three response variables were computed for

each data matrix, yielding the results shown in Table 1. As indicated,

most of the correlations are statistically significant, implying that

a genuine, if modest, overall relationship does exist among these

variables. On the whole, frequency is about equally correlated with

both force variables, while the correlation of mean peak force with LFV

is somewhat higher than this.

It should be noted, however, that the correlations just reported

between response rate and response force over arrays of single obser-

vations on these variables are not the relations visually apparent in

Figures 5 and 6. Rather, the latter are the covariations of the mean

values of frequency and force across sub-intervals as a result of the

joint dependence of these variables upon time since last reinforcement.

This latter variable, which may be construed as a stimulus variable

whose behavioral effects are established by the schedule of reinforce-

ment, operationally has ten values in this experiment, i.e., the 10

successive sub-intervals in an FI period, and will henceforth be referred

to as the "sub-interval pacing" variable (SIP). (The joint dependence of

Table 1

Total Coefficients of Correlation Among Response Rate,
Response Force, and Force Variation, Broken Down by Ss
and Experimental Phases

Subject:		3		7		8		12		Average
Phase:		I	II	I	II	I	II	I	II	
Correlation:										
rate/force		.501*	.329*	.163	.133	.545*	.689*	.143	.291*	.349
rate/LFV		.327*	.380*	.297*	.163	.143	.531*	.288*	.272*	.300
force/LFV		.247**	.626*	.572*	.627*	.347*	.700*	.372*	.644*	.516

* $p < .01$, ** $p < .05$, based on a two-tailed test.

the response measures on SIP phase II combines the effect of two factors--variation related to decreasing time to reinforcement within the interval and variation related to the $S^D - S^\triangle$ conditions--only the first of which is reflected by SIP in phase I.)

Each correlation listed in Table 1 may be construed as a composite of (1) relationship induced between the variables by their mutual dependence on SIP, and (2) whatever residual correlation exists independently of the sub-interval effect. These constituent correlations may be examined separately by partitioning each observation on each measure in a given matrix into two orthogonal components, the value of that variable regressed across sub-intervals (i.e., the variable's mean value across days in that sub-interval) and the difference between the observed score and the sub-interval regressed component. Correlations among the three variables for these two components were computed separately, utilizing the previously described data matrices, with the results shown in Table 2 for correlations due to SIP and Table 3 for the residual correlations.

The SIP - induced correlations shown in Table 2 are large, indicating high positive relationships in all cases. These correlations specify the degree to which rate and force are similarly affected by sub-interval pacing, as visible in Figures 5 and 6. In striking contrast, the residual correlations between frequency and the force variables with SIP partialled out are quite small, in some cases indicating a complete absence of relationship. These results suggest that the relation of frequency to both force variables arises almost exclusively from their joint dependence upon SIP. On the other hand, the relation of force to LFV is not so

Table 2

Correlations among the Sub-interval Regressed Components of
Rate, Force and Force Variation

Subject:	3		7		8		12		Average
Phase:	I	II	I	II	I	II	I	II	
Correlation:									
Rate/force	.908	.781	.391	.626	.925	.973	.718	.507	.729
Rate/LFV	.708	.602	.803	.541	.548	.943	.799	.680	.703
Force/LFV	.736	.714	.549	.946	.516	.946	.595	.687	.711

Table 3

Residual Coefficients of Correlation among Frequency, Force and
Force Variation After Sub-interval Pacing (SIP) is Partioned Out

Subject:	3		7		8		12		Average
Phase:	I	II	I	II	I	II	I	II	
Correlation:									
Rate/force	.254	.072	.138	.047	.302	.331	.054	.313	.177
Rate/LFV	.159	.285	.175	.094	.073	.269	.298	.186	.174
Force /LFV	.070	.593	.578	.544	.280	.585	.365	.640	.457

dependent upon SIP. Residual correlations of force and LFV, as shown

in Table 3, are positive and generally high, indicating a substantial

relationship between the two force variables apart from that induced

by SIP.

Finally, it is of interest to note how effectively the various

response measures were controlled by SIP, insomuch as the coefficients

of variation mentioned earlier in this section suggest that frequency

may be more profoundly affected by SIP than is force. The degree to

which each response measure is dependent upon SIP is quantified by

eta (η), the correlation ratio, which describes how closely the indivi-

dual values of each variable approximates its curvilinear regression

upon SIP. Results of the calculation of eta are expressed in Table 4.

It will be noted that response frequency is in fact more effectively

controlled by SIP than is response force. The data also suggest that

these response measures are differentially sensitive to the variation

induced by SIP in the two phases with the correlation ratios for fre-

quency remaining substantially the same but those values for the two

force variables tending to increase from phase I to phase II.

Table 4

Correlation Ratios (eta) for Response Rate, Response
Force and Local Force Variation Regressed on SIP,
Broken Down by $\underline{S}$ and Phase

	Phase I			Phase II		
$\underline{Ss}$	Rate	Force	LFV	Rate	Force	LFV
3	.70	.63	.49	.69	.56	.64
7	.62	.29	.41	.50	.71	.58
8	.71	.58	.45	.84	.71	.59
12	.79	.19	.27	.80	.29	.33
Avg.	.71	.42	.41	.71	.57	.54

DISCUSSION

Two problems were central to this study: 1) the development of a
technique to record the free emission of keypeck response force; and
2) clarification of the relationship between response frequency and
response force, with particular reference to responding engendered
by a fixed-interval schedule of reinforcement. These problems will be
discussed in the light of the data described in the previous section.

With respect to the development of procedures for the empirical
observation of response force, the technique employed in this study
appears adequate for future experimental use. The response key depicted
in Figure 1 allowed for the recording of discrete response forces at
the relatively high response rates typically observed immediately prior
to the reinforced response under an FI schedule of reinforcement, and
the results show that force data so collected are sensitive to behavioral
control through fixed interval scheduling of reinforcement. It is not
known whether random effects in the present recording system contributed
significant variance to the force observations.

An improvement in the technique of response force observation
employed in this study which might facilitate the recording and treat-
ment of such data would be the use of a digital printer instead of the
Brush recorder to record the response amplitudes. The translation of
response forces from waveform to numerical values would not then be
subject to human error and the data-processing time would be lessened
considerably.

With respect to the response frequency data, $\underline{S}$s showed response pat-
terning similar to that reported by Dews (1962), except that the degree

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of stimulus control attained in the Dews study was not reached in
this experiment. Dews' $\underline{S}$s showed marked similarity in response
patterning and response frequency in both experimental phases, whereas
the response patterning of rate in the present study differed consi-
derably across $\underline{S}$s, particularly in the case of phase II responding
(cf. Figure 3). Dews does not specify the number of experimental
sessions per $\underline{S}$ that was required to attain this high degree of
stimulus control across $\underline{S}$s, so it is possible that the number of
experimental sessions experienced by $\underline{S}$s in the present study was less
than that experienced by Dews' $\underline{S}$s. It is further suggested that inclusion
of a limited hold of short duration into the reinforcement contingencies
used in the present experiment would have appreciably sharpened schedule
control of responding for $\underline{S}$s 3, 7, 12. That is to say, with the addi-
tional requirement that a response must occur within a specified period,
following completion of the interval component of the cycle, in order
to be reinforced (i.e., "limited hold"), the response rate and pat-
terning of that rate would have been more consistent across $\underline{S}$s.

In the present study, both rate and force tracked progression of the
interval and $S^D - S^\Delta$ conditions, thereby showing the response patterning
reported by Dews to be present on at least two response continua, fre-
quency and intensity. That response force tended to increase with time
from start of interval, and was generally higher in S^D periods than in
S^Δ periods, may be interpreted as illustrating the "declining retroactive
force-enhancing effect of the reinforcing stimuli." This evidence that
FI curvature is demonstrable using either rate or force measures does

not seem to elucidate the factors which underlie such response patterning.
"The important point is that schedule-controlled patterns of responding
are . . . jointly determined by interacting environmental conditions.
A single ubiquitous explanation of schedule performances is unlikely
to be adequate." (Morse, 1966). The force data do indicate however,
that explanation of FI responding based on inter-response time (IRT)
distributions is insufficient. Morse (1966) offers the following inter-
pretation of FI curvature: the time between response X and response Y
is considered a measurable, conditionable property of response Y,
called its inter-response time and that, as a result of differential
reinforcement in FI conditioning, the probability of reinforcement for
longer IRTs is greater early in the interval and the probability of
reinforcement for short IRTs is greater near completion of the interval.
If that which controls behavior is in fact the respective probability of
reinforcement for long IRTs early in the interval and short IRTs late
in the interval, then the force of individual responses should not
necessarily differentiate responses occurring at different times in
the FI. However, response force was observed to increase with time
from start of interval in the present study. It is suggested that the
increase of rate and force of responding throughout the interval indi-
cates differences in the propensity to make unitary responses occurring
as a function of proximity to reinforcement rather than a propensity to
respond differentially to interresponse times.

The S^D - S^Δ response force data reported in this study are at
variance with the effects of continuous reinforcement (CRF) S^D - S^Δ

discriminations on rat lever-depression force as previously reported

in the literature. Notterman and Block (1960) reported response

force to be higher and response frequency to be lower during S^{Δ} when

compared to S^D. Herrick (1963) trained rats to depress a lever in the

presence of a houselight, rewarding each lever depression beyond a

lever displacement value of 1 on an increasing scale of 8 and did not

reinforce any responses when the light was off. He reported mean lever

displacement to be greater when the light was off (S^{Δ}) and response

frequency to be greater when houselight was present (S^D). There are

several reasons why these two previous studies might have obtained a

different $S^D - S^{\Delta}$ force relationship than the one found here: 1) The

rat and the pigeon may respond differently to an $S^D - S^{\Delta}$ discrimination

situation. 2) The processes governing the production of response force

are differentially affected by the methods of $S^D - S^{\Delta}$ stimuli introduction.

Terrace (1966) has demonstrated differences in discrimination performance

and emotional components of behavior produced by different methods of

introducing the S^D and S^{Δ}. The procedure used to train the discrimination

in both Notterman, et al. and the Herrick studies is analogous to the

"discrimination learning with errors" procedure reported by Terrace to

engender considerable emotional behavior and relatively poor performance

by the pigeon. Their procedure may be described as producing extinction

of responding in the presence of S^{Δ}, rather than arranging for no S^{Δ}

responding at outset of training, as in the Terrace "errorless" procedure,

thereby resulting in frustration effects, raising response force accor-

dingly. 3) Somewhat related to the last point is the possibility that

the determinants of response force during acquisition are quite different in kind or degree from those at a stable behavioral baseline. The data reported in the present study were recorded following attainment of a frequency-based criterion of behavioral stability while the Notterman and Block ▬▬▬ data appear to have been gathered during acquisition of the discrimination. This interpretation is consistent with the adaptation explanation of increased response force during S^Δ offered by Notterman and Mintz (1965) that "biological organisms are exposed from birth to reinforcement contingencies in which successively more vigorous responding tends to produce reinforcement," (p. 104), hence the animal presses harder during acquisition. Acquisition may be considered for the $\underline{S}$ as "learning he will never be reinforced when S^Δ is present" thus exhibiting lessened rate and force. Acquisition of the S^D - S^Δ discrimination may be operationally defined therefore as complete when response force and rate are considerably and consistently less during S^Δ than during S^D, the suggestion being that propensity to respond in the face of non-reinforcement, as determined by emotional factors, is "shaped-out" by repeated experience with a particular S^D - S^Δ discrimination.

A number of general trends were present in the relationship of response rate to response force in this experiment, the first being that both rate and the two force variables seem to be affected in similar fashion by the progression of time in the FI. The three variables tend to increase in value with time since last reinforcement and in S^D periods compared to S^Δ periods but, apart from this common dependence on schedule control, there is no effective residual relation between rate and the two

force variables, indicating that the correlations of response rate

with response force and LFV are mediated solely by internal controls

which respond to scheduling of reinforcement. The force variables,

on the other hand, have something more in common than the factors

controlled by SIP. Secondly, response rate was more effectively controlled

by the reinforcement schedule in this study (FI 500" with a superimposed

$S^D - S^\triangle$ discrimination) than was response force. This relationship is

complicated by the observation that for S7 in phase II, response force

differentiated the discrimination conditions better than did rate.

Any discussion of the relative merits of response rate and response

force as basic data for the empirical analysis of behavior should note

that the two measures have different temporal characteristics. Peak

force on the one hand quantifies a momentary and unitary response event

whereas rate is a quantification of an averaged number of response

events, i.e., number of events per unit of time. Therefore, it seems

reasonable to assume peak force to better assess moment to moment

changes effected by conditions of the organism whether environmental,

such as onset of shock, or internal, such as "drive level". Response

rate is more sensitive to behavioral changes produced by environmental

changes occurring over extended periods, as is evidenced by the data

in the present investigation.

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